

South Dakota State University

## Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange

---

Electronic Theses and Dissertations

---

1972

### A Special-purpose Computer and Console to Assist Blind Bowlers

Gary L. Wilhelm

Follow this and additional works at: <https://openprairie.sdstate.edu/etd>

---

#### Recommended Citation

Wilhelm, Gary L., "A Special-purpose Computer and Console to Assist Blind Bowlers" (1972). *Electronic Theses and Dissertations*. 4851.

<https://openprairie.sdstate.edu/etd/4851>

This Thesis - Open Access is brought to you for free and open access by Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. For more information, please contact [michael.biondo@sdstate.edu](mailto:michael.biondo@sdstate.edu).



164  
A SPECIAL-PURPOSE COMPUTER AND CONSOLE  
TO ASSIST BLIND BOWLERS

BY

GARY L. WILHELM

A thesis submitted  
in partial fulfillment of the requirements for the  
degree Master of Science, Major in  
Electrical Engineering, South Dakota  
State University

1972

LB 2385

W 649

c.2



A SPECIAL-PURPOSE COMPUTER AND CONSOLE

TO ASSIST BLIND BOWLERS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor

Date

Head, Electrical  
Engineering Department

Date

1. The first part of the paper is devoted to a study of the properties of the function  $f(x)$  defined by the equation

$$f(x) = \int_0^x \frac{1}{1+t^2} dt, \quad (1)$$

where  $x$  is a real number. It is shown that the function  $f(x)$  is continuous and differentiable for all values of  $x$ . The derivative of  $f(x)$  is found to be  $f'(x) = \frac{1}{1+x^2}$ . It is also shown that the function  $f(x)$  is bounded for all values of  $x$ . The maximum value of  $f(x)$  is found to be  $\frac{\pi}{2}$ .

2. The second part of the paper is devoted to a study of the properties of the function  $g(x)$  defined by the equation

$$g(x) = \int_0^x \frac{t}{1+t^2} dt, \quad (2)$$

where  $x$  is a real number. It is shown that the function  $g(x)$  is continuous and differentiable for all values of  $x$ . The derivative of  $g(x)$  is found to be  $g'(x) = \frac{x}{1+x^2}$ . It is also shown that the function  $g(x)$  is bounded for all values of  $x$ . The maximum value of  $g(x)$  is found to be  $\frac{\pi}{4}$ .



## ACKNOWLEDGMENTS

The author expresses sincere appreciation to Dr. F. C. Fitchen and Dr. D. E. Sander for their advice, guidance, and suggestions, and to the National Science Foundation for their support. Special gratitude is extended to my wife, Carolyn, for her encouragement, patience and help. Thanks are also given to my brother George, for helping with the drafting.

G. L. W.

MEMORANDUM

TO : THE SECRETARY OF THE ARMY  
FROM : THE CHIEF OF STAFF  
SUBJECT: [Illegible]  
[Illegible text follows]

[Illegible]

## TABLE OF CONTENTS

Chapter	Page
GLOSSARY OF TERMS . . . . .	vi
I. Introduction to Blind Bowling . . . . .	1
II. General Design Considerations . . . . .	4
A. Scorekeeping for Bowling . . . . .	4
B. A Scorekeeping Algorithm . . . . .	7
C. Verification of the Algorithm . . . . .	16
D. General Specifications . . . . .	22
III. Hardware Design . . . . .	24
A. General Discussion . . . . .	24
B. Information Displayed . . . . .	24
C. Discussion of the Major Sections . . . . .	28
1. Sequencer I/KT Counter Decoding/Display . . . . .	28
2. Operate Sequencer . . . . .	29
3. Pin Counter/Display . . . . .	30
4. Memory/Man-Up Counter/Display . . . . .	30
5. Arith/Display Section . . . . .	30
D. Detailed Logic Design . . . . .	35
IV. Design of the Tactile-Audio Console for Blind Bowlers . . . . .	43
V. Areas Needing More Work . . . . .	49
VI. Summary of Conclusions and Recommendations . . . . .	53
BIBLIOGRAPHY . . . . .	54

CHAPTER III

THE first of the three main divisions of the subject is the history of the country. This is a very important part of the study, and it is one which has attracted the attention of many writers. The second division is the description of the country, and the third is the account of the people who live there. These three divisions are the main parts of the study, and they are all of great importance. The history of the country is a very interesting subject, and it is one which has attracted the attention of many writers. The description of the country is a very important part of the study, and it is one which has attracted the attention of many writers. The account of the people who live there is a very important part of the study, and it is one which has attracted the attention of many writers.

## LIST OF FIGURES

Figure 1.	System Block Diagram . . . . .	2
Figure 2.	Scoring by Frame . . . . .	5
Figure 3.	Game Endings . . . . .	6
Figure 4.	Flow Chart in Words . . . . .	8
Figure 5.	Flow Chart in Fortran . . . . .	9
Figure 5-A	Examples Correlated with Various Paths . . . . .	10
Figure 5-B	Path to Score an Ordinary Frame with No Previous Strikes or Spare . . . . .	11
Figure 5-C	Paths Followed if Frame Being Scored is a Strike or Spare . . . . .	12
Figure 5-D	Path to Compute a Previous Space Total or Game Total with a Spare in the Tenth Frame . . . . .	13
Figure 5-E	Path to Compute Total for One Previous Strike . . . . .	14
Figure 5-F	Path to Compute Total for Strike, Two Frames Back; Or to End the Game with Two Strikes in the Ninth and Tenth Frames . . . . .	15
Figure 6	Fortran Program . . . . .	16
Figure 7-A	Algorithm Test: Strike Ending . . . . .	18
Figure 7-B	Algorithm Test: Perfect Game . . . . .	19
Figure 7-C	Algorithm Test: Spare Ending . . . . .	20
Figure 7-D	Algorithm Test: Ordinary Ending . . . . .	21
Figure 8.	General Block Diagram . . . . .	25
Figure 9.	Block Diagram Showing Interconnections . . . . .	27
Figure 10.	8-4-2-1 Binary Coded Decimal . . . . .	31
Figure 11.	B.C.D. Sums Needing Correction . . . . .	32
Figure 12.	Karnaugh Map . . . . .	33
Figure 13.	B.C.D. Adder Stage . . . . .	34

APPENDIX

1	...	...
2	...	...
3	...	...
4	...	...
5	...	...
6	...	...
7	...	...
8	...	...
9	...	...
10	...	...
11	...	...
12	...	...
13	...	...
14	...	...
15	...	...
16	...	...
17	...	...
18	...	...
19	...	...
20	...	...
21	...	...
22	...	...
23	...	...
24	...	...
25	...	...
26	...	...
27	...	...
28	...	...
29	...	...
30	...	...
31	...	...
32	...	...
33	...	...
34	...	...
35	...	...
36	...	...
37	...	...
38	...	...
39	...	...
40	...	...
41	...	...
42	...	...
43	...	...
44	...	...
45	...	...
46	...	...
47	...	...
48	...	...
49	...	...
50	...	...
51	...	...
52	...	...
53	...	...
54	...	...
55	...	...
56	...	...
57	...	...
58	...	...
59	...	...
60	...	...
61	...	...
62	...	...
63	...	...
64	...	...
65	...	...
66	...	...
67	...	...
68	...	...
69	...	...
70	...	...
71	...	...
72	...	...
73	...	...
74	...	...
75	...	...
76	...	...
77	...	...
78	...	...
79	...	...
80	...	...
81	...	...
82	...	...
83	...	...
84	...	...
85	...	...
86	...	...
87	...	...
88	...	...
89	...	...
90	...	...
91	...	...
92	...	...
93	...	...
94	...	...
95	...	...
96	...	...
97	...	...
98	...	...
99	...	...
100	...	...



Figure 14.	Sequencer I Flow . . . . .	36
Figure 15.	Sequencer I/KT Counter/Master Clear . . . . .	37
Figure 16.	Operate Sequencer . . . . .	38
Figure 17.	Pin Counter . . . . .	39
Figure 18.	Memory and Man-Up Counter . . . . .	40
Figure 19.	Arith/Display . . . . .	41
Figure 20.	Arith II . . . . .	42
Figure 21.	Tactile-Audio Console . . . . .	44
Figure 22.	Comparison of Console with Conventional Bowling Frames . . . . .	47
Figure 23.	Bowling Calculator . . . . .	52



## GLOSSARY OF TERMS

FRAME: One of the ten divisions of a game; also, a box used for scoring.

STRIKE: Knocking down all ten pins with the first ball rolled.

SPARE: Knocking over all the pins with two balls in any one frame; also called conversion.

SPLIT: Two or more pins left standing after the first roll, without the usual pins standing between.

ERROR: A missed spare, same as a blow.

FOUL: Touching anywhere beyond the foul line.

GAME: Ten frames.

ALGORITHM: A procedure, rule, or method.

DIGITAL: A number, a digit.

SEQUENTIAL: A logical circuit where the output is a function of both present and past inputs.

BINARY: A method of counting using only two symbols.

8-4-2-1 Binary Coded Decimal: (B.C.D.) A method of expressing a decimal number with each decimal digit coded in binary.

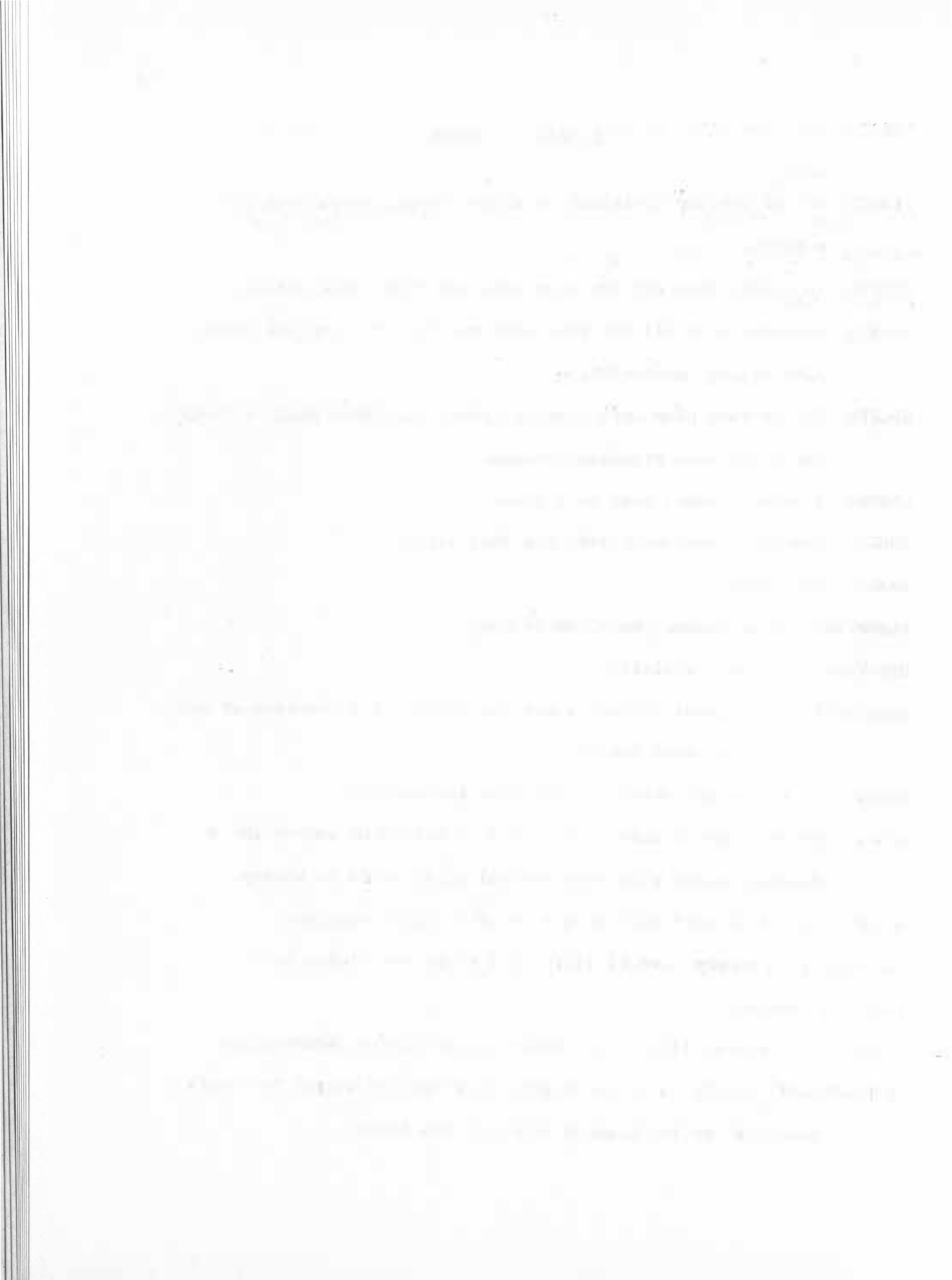
MONOSTABLE: A circuit with an output of a fixed duration.

FLIP-FLOP: A memory circuit which will store one binary bit.

FLAG: A reminder.

REGISTERS: Several flip-flops used to store binary information.

COMBINATIONAL LOGIC: A logic circuit in which the output is solely dependent on the present state of the inputs.



"AND" GATE: The AND output is high if and only if all the inputs are high.

"ON" GATE: The output is low if and only if all inputs are low.

TACTILE: Perceived by the sense of touch.

AUDIO: Sound.

1897

1

THE UNIVERSITY OF CHICAGO PRESS

1897

1897

THE UNIVERSITY OF CHICAGO PRESS

THE UNIVERSITY OF CHICAGO PRESS

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

1897

## CHAPTER I

### Introduction to Blind Bowling

In 1951 the American Blind Bowling Association (referred to as the A.B.B.A.) was formed. The A.B.B.A. is the official sanctioning organization for blind ten-pin bowlers and blind bowling leagues in the United States and Canada. Blind bowling has grown in popularity, and today the A.B.B.A. has more than one hundred affiliated leagues. Every year, a National Championship Blind Bowling Tournament is conducted which usually attracts more than a thousand blind bowlers from the United States and Canada.

Why is bowling so popular among the blind? There are many reasons. First of all, the blind bowlers can enjoy the game and benefit from the physical activity while competing with sighted bowlers on a nearly equal competitive basis. Bowling is an excellent social outlet because it brings people together in a mildly competitive situation and exposes them to the varied experiences of winning and losing. Finally, the process of bowling, whether done well or not, builds self-confidence which usually manifests itself both on and off the bowling lanes.

One might ask: "How do the blind bowl?" Most of the totally blind bowlers rely on a bowling guide rail to orient themselves. In order to know which pins have been knocked down and keep score, the blind person usually has to rely on a sighted person. As previously mentioned, it is good for blind and sighted bowlers to participate in bowling together, but what if a blind bowler wants to bowl and a sighted bowler is not available to tell him which pins have been





knocked down, and to keep score? There is a need for special equipment, so that blind bowlers can bowl independently. Because of recent advances in electronic circuitry, it is now possible to produce such special equipment much more economically than just a few years ago. [1]

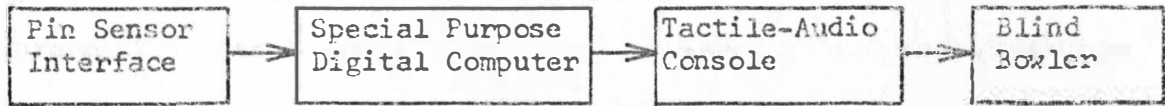


Figure 1. System Block Diagram.

The System Block Diagram in Figure 1. illustrates the overall concept involved in assisting blind bowlers. This thesis is a step in the development of equipment to enable the blind to bowl independently. The work reported here deals specifically with the design of a special purpose digital computer and the tactile-audio console.

The design starts with a pin sensor interface. Since it would be necessary to interface with equipment made by several different manufacturers, several different interfaces would probably be needed. To develop a pin sensor that is independent of existing equipment would require a considerable effort, and hence that task is left for a separate project.

The design of a special purpose digital computer is included in this thesis. A minicomputer could have been used, but all the capabilities of a minicomputer are not needed, and the special purpose unit would be more economical.

The Tactile-Audio Console was designed to communicate the essential information to the blind bowler. Most of the information is transmitted by tactile means, but a buzzer is also included to get

The first part of the paper is devoted to the study of the properties of the function  $f(x)$  defined by the equation

$$f(x) = \begin{cases} 1 & \text{if } x \text{ is a rational number} \\ 0 & \text{if } x \text{ is an irrational number} \end{cases}$$

It is well known that this function is nowhere continuous. In fact, for any point  $x_0$  and any  $\epsilon > 0$ , there is always a rational number  $x$  such that  $|x - x_0| < \delta$  and  $|f(x) - f(x_0)| = 1 > \epsilon$ . This shows that  $f(x)$  does not satisfy the  $\epsilon$ - $\delta$  criterion for continuity at any point.

However, the function  $f(x)$  is continuous at every irrational point  $x_0$  if we consider it as a function of a rational variable. In other words, if we restrict our attention to the rational numbers, then  $f(x)$  is the constant function  $f(x) = 1$  for all rational  $x$ . This function is, of course, continuous.

This example illustrates the importance of the domain of a function when discussing its properties. A function that is discontinuous on a large set can be continuous when restricted to a smaller, more carefully chosen domain.

Another interesting property of the function  $f(x)$  is that it is measurable. In the theory of Lebesgue integration, a function is said to be measurable if the set of points where it takes values greater than a certain number is a measurable set. For the function  $f(x)$ , this set is either empty or the set of all rational numbers, both of which are measurable.

Finally, it is worth noting that the function  $f(x)$  is an example of a function that is not Riemann integrable but is Lebesgue integrable. The Riemann integral requires the function to be continuous almost everywhere, which  $f(x)$  fails to satisfy. The Lebesgue integral, on the other hand, is more general and can handle functions like  $f(x)$ .

## CHAPTER II

### General Design Considerations

#### A. Scorekeeping for Bowling

The scorekeeping procedures used in bowling were studied thoroughly before the design of the scorekeeping logic was begun. To simplify this design, the decision was made not to indicate splits in any special way, and also not to indicate errors or fouls or gutter balls. Splits and errors will be apparent from the pin display on the console; fouls and gutter balls can be detected by the sound. In this first model, no provisions are made to compute handicaps or perform any special functions for tournament use.

Figure 2 gives a brief summary of the scoring of bowling frames under various conditions. The reader who needs more basic information about bowling is referred to a book such as: Bowling, by Lou Bellissimo and Larry L. Neal, of the Prentice-Hall sport series.

In addition to the variations in scoring shown in Figure 2, there are further complications due to the various game endings when a spare or strike is bowled in the tenth frame. Figure 3 gives a summary of the various game endings.

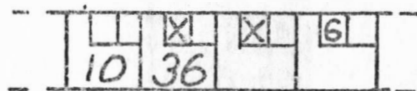
The scorekeeping function in bowling is basically a matter of first, scoring by frame as shown in Figure 2, then properly ending the game as shown in Figure 3.

A scoring algorithm, or procedure for keeping bowling scores, was derived, programmed in Fortran, and verified on the I.B.M. 360 computer. One pass is made through the algorithm for each of the ten frames. Different paths are followed, depending on the strike/spare history

the blind bowler's attention and to notify him if he makes a strike or a spare.

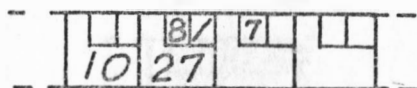
Considerable difficulty was encountered while looking for articles on this topic in the literature. No articles were found on special computer equipment to assist blind bowlers. In fact, the only information that could be related to computerized scoring of bowling games was found in a patent search. [2] The first patent in this area was filed in 1961, and the available information indicates that the first commercial score-keeping computer for sighted bowlers was introduced in 1970. The information in these patents was written in legal terms and either obscure or sketchy. Because of this fact, and the differences between a scoring unit for sighted bowlers and a unit for blind bowlers, no information from these patents was used in this thesis.

## STRIKE

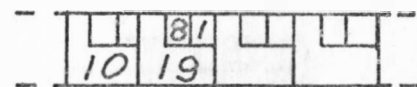


A strike is scored by adding ten pins to the previous total, plus the total pins downed by the next two bonus shots.

## SPARE



A spare is scored by adding ten pins to the previous total, plus the pins downed by the next bonus shot.

NO STRIKE  
OR SPARE

If all ten pins are not knocked down with both balls, the frame is scored by adding the total of the pins downed with both balls to the previous total.

Figure 2. Scoring by Frame. [3]

TENTH FRAME  
STRIKE

9	10										
<table><tr><td></td><td></td><td>X</td><td>2</td><td>1</td></tr><tr><td>150</td><td>163</td><td></td><td></td><td></td></tr></table>			X	2	1	150	163				
		X	2	1							
150	163										

If the first ball in the tenth frame results in a strike, two bonus balls are rolled and used to compute the tenth frame or game total.

TENTH FRAME  
SPARE

9	10										
<table><tr><td></td><td></td><td>8</td><td>/</td><td>6</td></tr><tr><td>150</td><td>166</td><td></td><td></td><td></td></tr></table>			8	/	6	150	166				
		8	/	6							
150	166										

If the two tenth frame balls result in a spare, a third bonus ball is rolled and used to compute the tenth frame or game total.

NORMAL TENTH  
FRAME

9	10										
<table><tr><td></td><td></td><td>2</td><td>/</td><td></td></tr><tr><td>150</td><td>153</td><td></td><td></td><td></td></tr></table>			2	/		150	153				
		2	/								
150	153										

If there is neither a strike nor a spare in the tenth frame, the tenth frame or game total is the sum of the previous total and the total number of pins downed with both balls in the tenth frame.

Figure 3. Game Endings. [4]

and game ending. Figure 4 is a flow chart of this algorithm with the functions described in words; Figure 5 is the same flow chart except that the functions are given in Fortran computer language.

#### B. A Scorekeeping Algorithm

Instruction numbers have been added to Figure 5 at key points so that a correlation can be made to the program in Figure 6. The following definitions are also necessary to understand the flow charts:

ITOT1 is the last computed frame total.

ITOT2 is the new frame total being computed.

N1 is the number of pins downed by ball one in each frame.

N2 is the number of pins downed by the second ball of the frame.

KS1 is the first strike flag or reminder.

KS2 is the second strike flag or reminder.

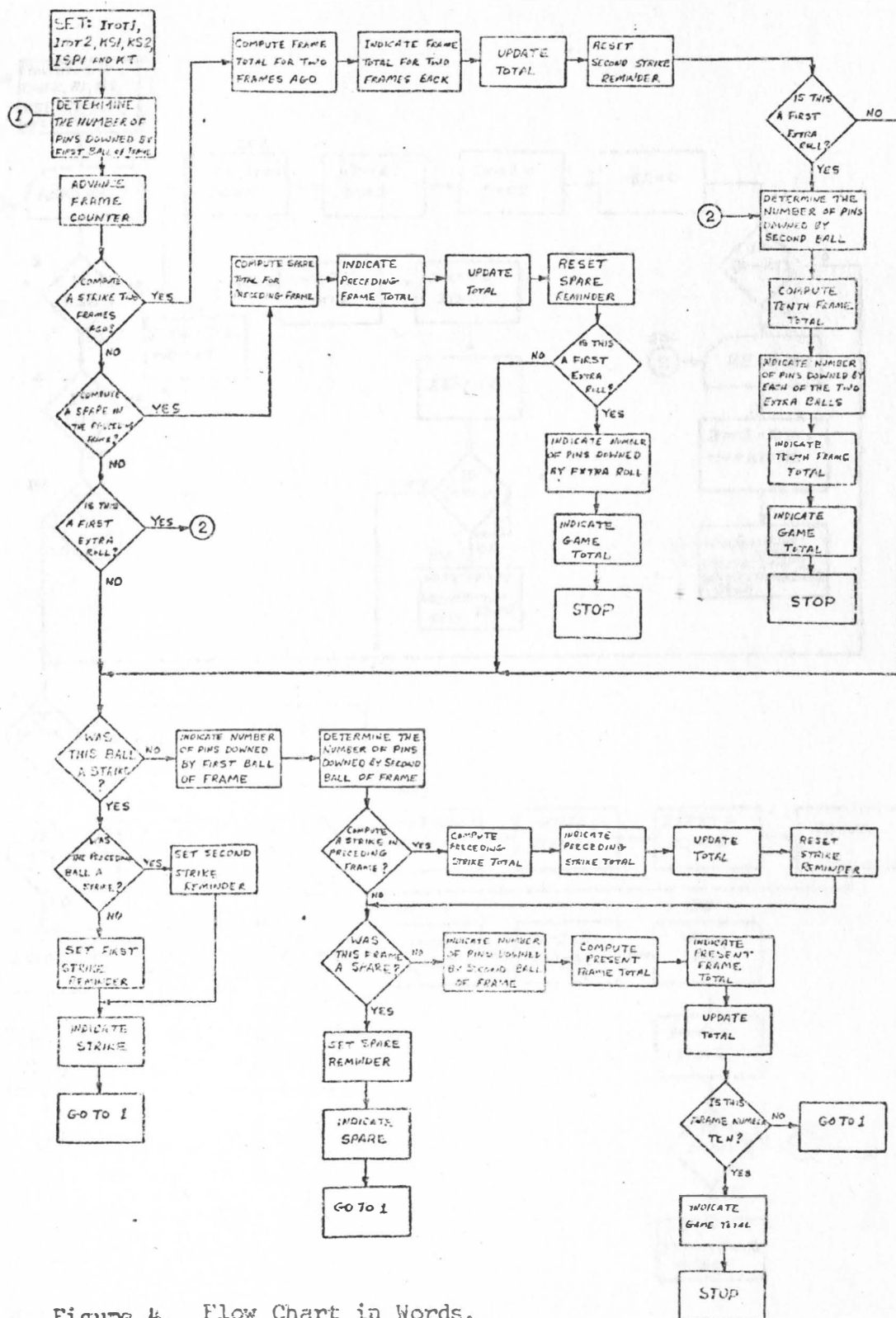
ISP1 is the spare flag or reminder.

KT is the number of the frame being bowled.

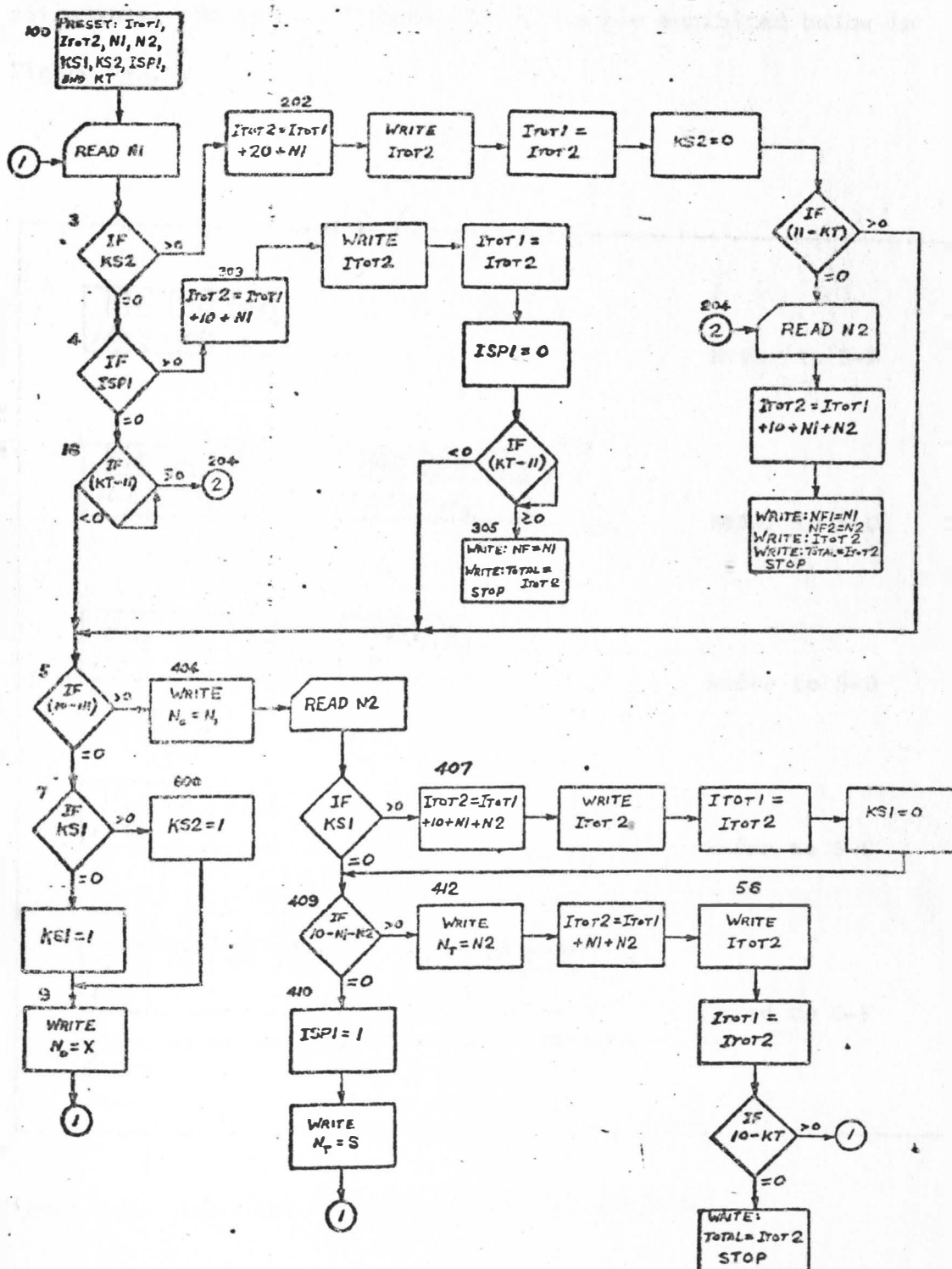
NF or NF1 is the first bonus ball in the tenth frame.

NF2 is the second bonus ball in the tenth frame.

TOTAL is a game total.







Figures 5-B through 5-F illustrate the paths followed for various situations. Examples of these situations are exhibited below in Figure 5-A.

54	31	21
100	104	?

Refer to 5-B

54	31	X
100	104	

or

54	31	2/
100	104	

Refer to 5-C

42	3/	2
100	?	

or

42	3/2
100	?

Refer to 5-D

12	X	
100	?	

Refer to 5-E

12	X	X	2
100	?		

or

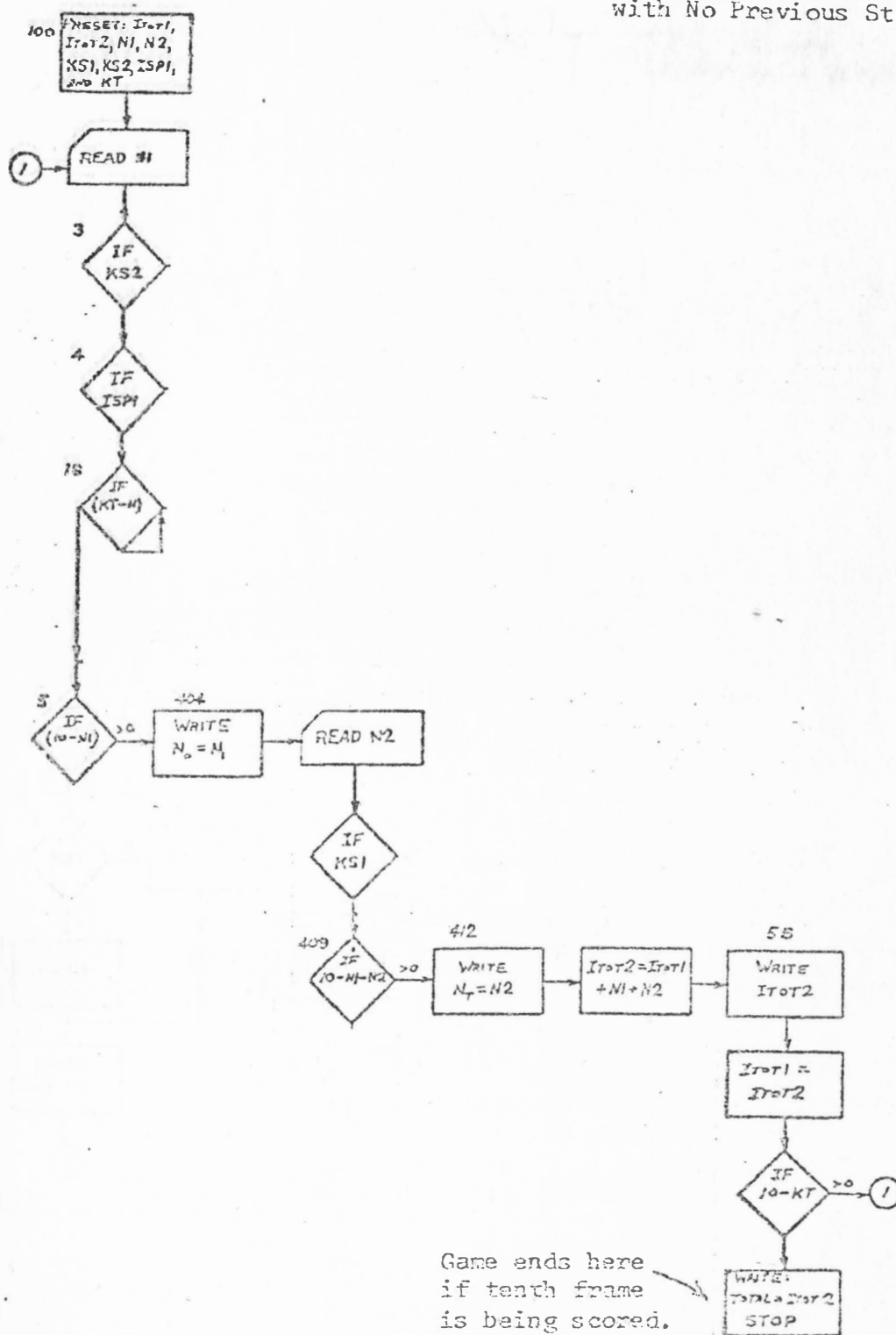
12	X	X	2
100	?		

Refer to 5-F

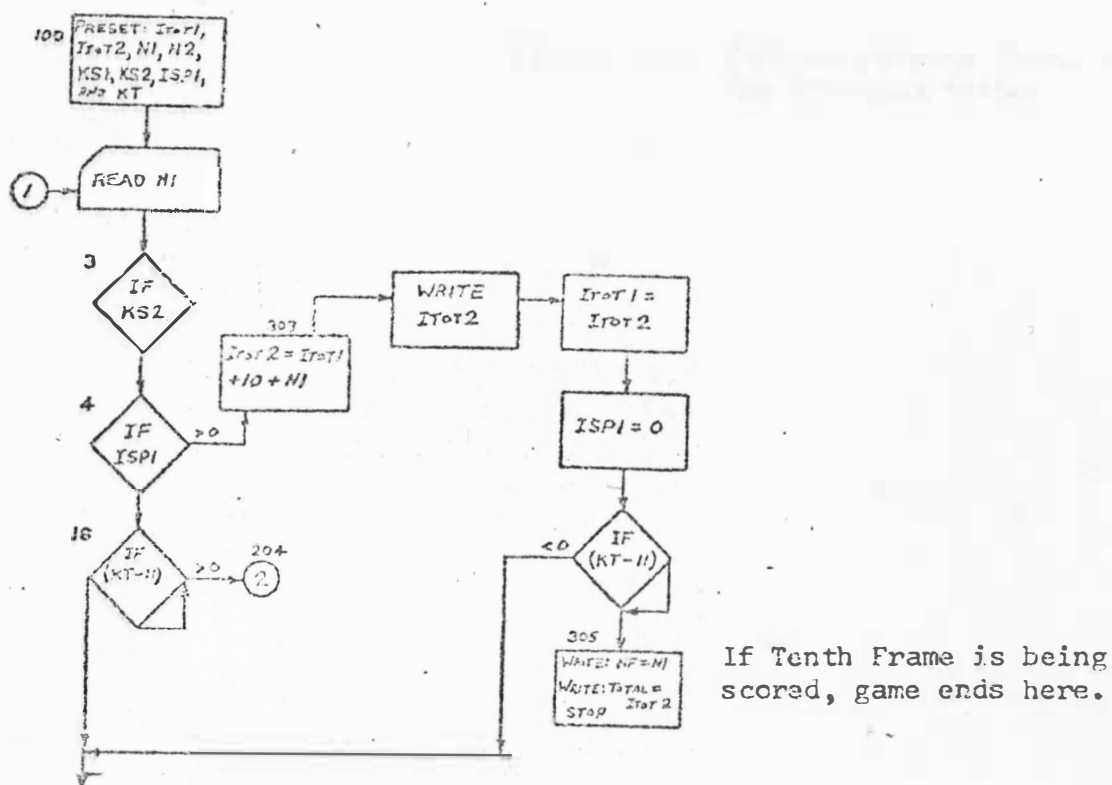
Question marks indicate totals computed in the course of following the paths indicated in Figures 5-B through 5-F.

Figure 5-A. Examples Correlated with Various Paths.

Figure 5-B. Path to Score an Ordinary Frame with No Previous Strikes or Spare.



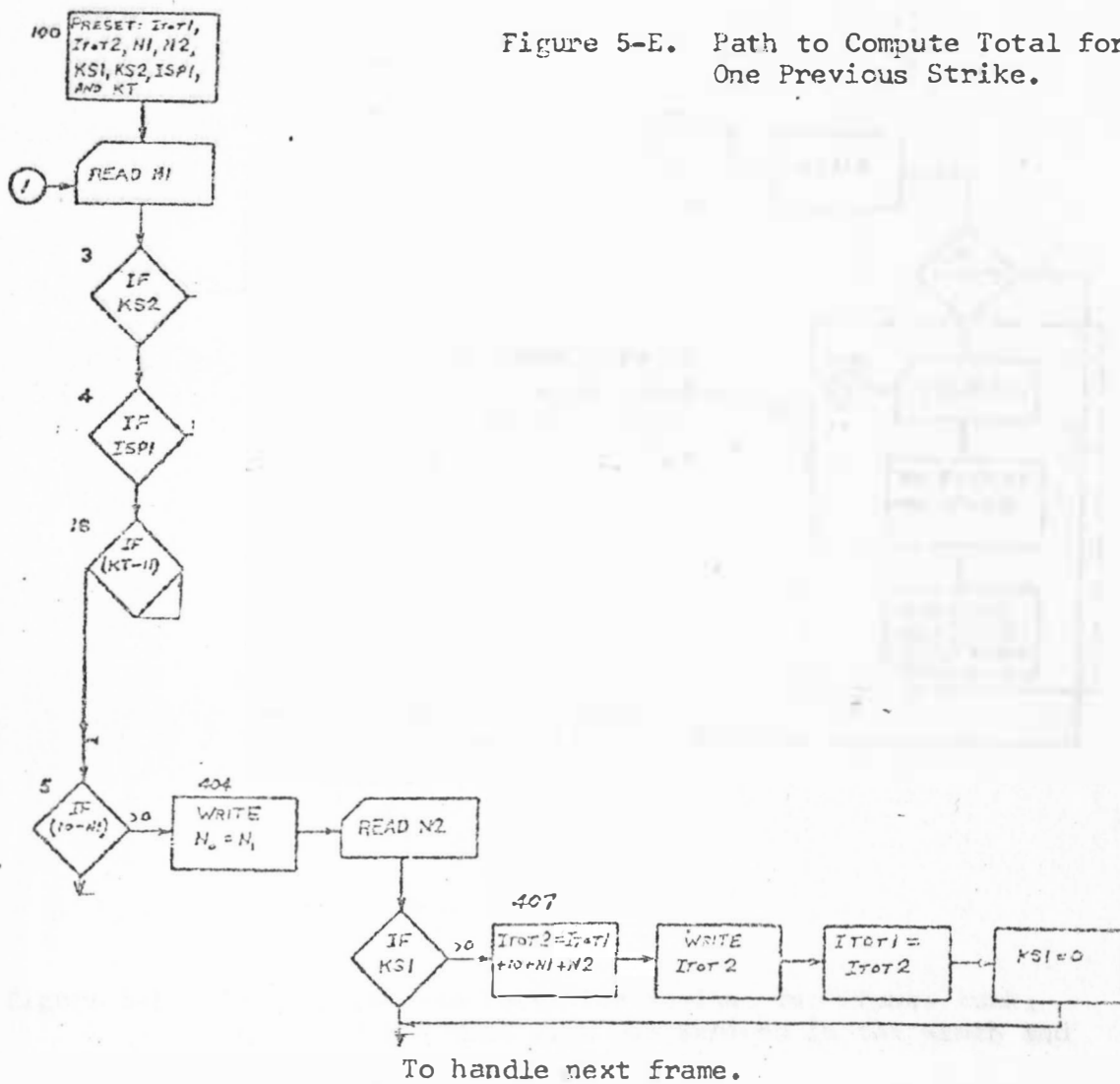




To handle next frame, after second ball is rolled.

Figure 5-D. Path to Compute a Previous Spare Total or Game Total with a Spare in the Tenth Frame.

Figure 5-E. Path to Compute Total for One Previous Strike.



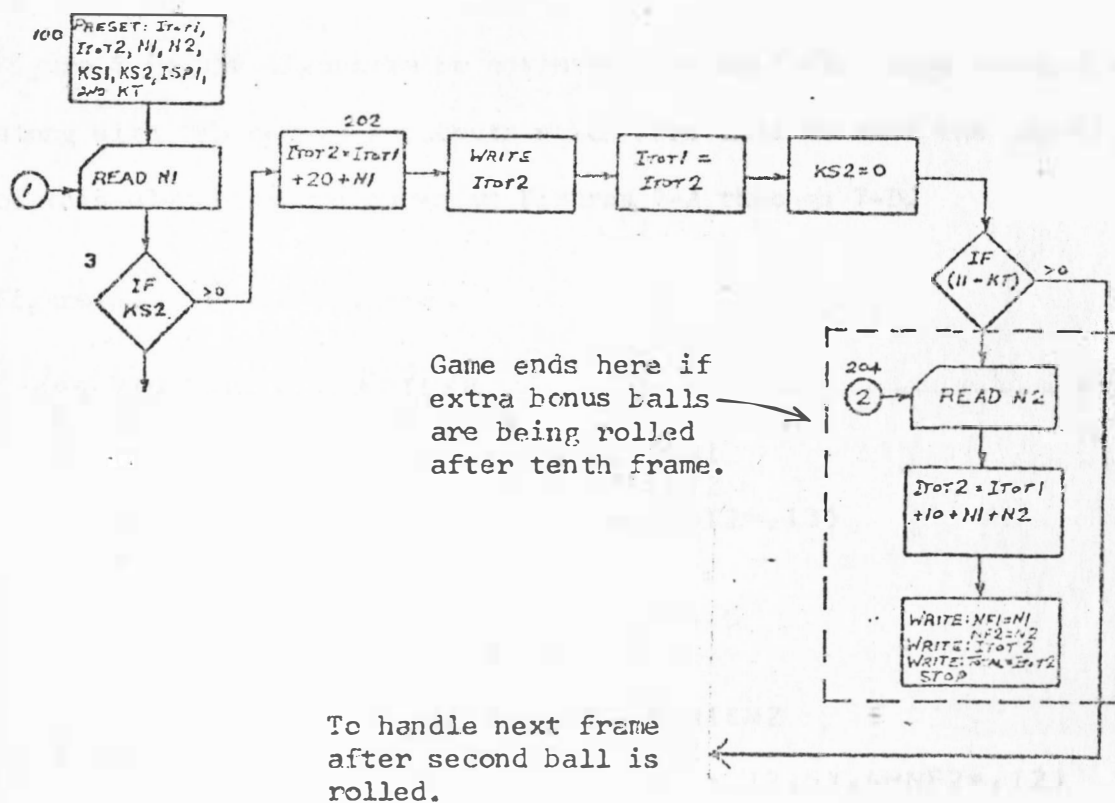


Figure 5-F. Path to Compute Total for Strike, Two Frames Back, Or to End the Game with Two Strikes in the Ninth and Tenth Frames.

### C. Verification of the Algorithm

Figure 6 is the algorithm in computer program form. Some bowling games along with the computer outputs which were used to test the capability of this algorithm are shown in Figures 7-A through 7-D.

Figure 6. Fortran Program .

```

BPS FORTRAN D COMPILER
S.0001      GO TO 1
S.0002      202      ITOT2=ITOT1&20&N1
S.0003      WRITE(6,203)ITOT2
S.0004      203      FORMAT(1H0,6HITOT2=,I3)
S.0005      ITOT1=ITOT2
S.0006      KS2=0
S.0007      IF(11-KT)204,204,5
S.0008      204      READ(5,207)N2
S.0009      207      FORMAT(I2)
S.0010      ITOT2=ITOT1&10&N1&N2
S.0011      WRITE(6,23)N1,N2
S.0012      23      FORMAT(1H0,4HNF1=,I2,5X,4HNF2=,I2)
S.0013      WRITE(6,205)ITOT2
S.0014      205      FORMAT(1H0,6HITOT2=,I3)
S.0015      WRITE(6,206)ITOT2
S.0016      206      FORMAT(1H0,6HTOTAL=,I3)
S.0017      GO TO 100
S.0018      303      ITOT2=ITOT1&10&N1
S.0019      WRITE(6,304)ITOT2
S.0020      304      FORMAT(1H0,6HITOT2=,I3)
S.0021      ITOT1=ITOT2
S.0022      ISP1=0
S.0023      IF(KT-11)5,305,305
S.0024      305      WRITE(6,24)N1
S.0025      24      FORMAT(1H0,3HNF=,I2)
S.0026      WRITE(6,306)ITOT2
S.0027      306      FORMAT(1H0,6HTOTAL=,I3)
S.0028      GO TO 100
S.0029      100      ITOT2=0
S.0030      ITOT1=0
S.0031      KS2=0
S.0032      KS1=0
S.0033      KT=0
S.0034      ISP1=0
S.0035      N1=0
S.0036      N2=0

```



Figure 6. (continued)

```

S.0037      1      READ(5,2)N1
S.0038      2      FORMAT(I2)
S.0039      KT=KT&1
S.0040      3      IF(KS2)4,4,202
S.0041      4      IF(ISP1)16,16,303
S.0042     16      IF(KT-11)5,204,204
S.0043      5      IF(10-N1)7,7,404
S.0044     404     WRITE(6,405)N1
S.0045     405     FORMAT(1H0,3HNO=,I2)
S.0046      READ(5,406)N2
S.0047     406     FORMAT(I2)
S.0048      IF(KS1)409,409,407
S.0049     407     ITOT2=ITOT1&10&N1&N2
S.0050      WRITE(6,408)ITOT2

S.0051     408     FORMAT(1H0,6HITOT2=,I3)
S.0052      ITOT1=ITOT2
S.0053      KS1=0
S.0054     409     IF(10-N1-N2)410,410,412
S.0055     410     ISP1=1
S.0056      WRITE(6,411)
S.0057     411     FORMAT(1H0,4HNT=S)
S.0058      GO TO 1
S.0059     412     WRITE(6,413)N2
S.0060     413     FORMAT(1H0,3HNT=,I2)
S.0061      ITOT2=ITOT1&N1&N2
S.0062      WRITE(6,414)ITOT2
S.0063     414     FORMAT(1H0,6HITOT2=,I3)
S.0064      ITOT1=ITOT2
S.0065      IF(10-KT)56,56,1
S.0066     56     WRITE(6,57)ITOT2
S.0067     57     FORMAT(1H0,6HTOTAL=,I3)
S.0068      GO TO 100
S.0069      7      IF(KS1)8,8,800
S.0070     800     KS2=1
S.0071      GO TO 9
S.0072      8      KS1=1
S.0073      9      WRITE(6,10)
S.0074     10     FORMAT(1H0,4HNO=X)
S.0075      GO TO 1
S.0076      END

```

Figure 7-A. Algorithm Test: Strike Ending.

5/	9-	X	42	7-	5/	7/	X	36	X	55
19	28	44	50	57	74	94	113	122	142	

NO= 5

NT=5

ITOT2= 19

NO= 9

NT= 0

ITOT2= 28

NO=X

NO= 4

ITOT2= 44

NT= 2

ITOT2= 50

NO= 7

NT= 0

ITOT2= 57

NO= 5

NT=5

ITOT2= 74

NO= 7

NT=5

ITOT2= 94

NO=X

NO= 3

ITOT2=113

NT= 6

ITOT2=122

NO=X

NF1= 5      NF2= 5

ITOT2=142

TOTAL=142



Figure 7-C. Algorithm Test: Spare Ending.

34	9-	5/	0-	X	1/	X	62	236/1
7	16	26	26	46	66	84	92	97.108

NO= 3

NT= 4

ITOT2= 7

NO= 9

NT= 0

ITOT2= 16

NO= 5

NT=S

ITOT2= 26

NO= 0

NT=0

ITOT2= 26

NO=X

NO= 1

ITOT2= 46

NT=S

ITOT2= 66

NO=X

NO= 6

ITOT2= 84

NT= 2

ITOT2= 92

NO= 2

NT= 3

ITOT2= 97

NO= 6

NT=S

ITOT2=108

NF= 1

TOTAL=108

Figure 7-B. Algorithm Test: Ordinary Ending.

6/	54	8-	X	42	5/	6/	8-	2344
15	24	32	48	54	70	88	96	101 109

NO= 6

NT=S

ITOT2= 15

NO= 5

NT= 4

ITOT2= 24

NO= 3

NT= 0

ITOT2= 32

NO=X

NO= 4

ITOT2= 48

NT= 2

ITOT2= 54

NO= 5

NT=S

ITOT2= 70

NO= 6

NT=S

ITOT2= 88

NO= 8

NT= 0

ITOT2= 96

NO= 2

NT= 3

ITOT2=101

NO= 4

NT= 4

ITOT2=109

TOTAL=109

#### D. General Specifications

From this algorithm, the very general functional specifications of the scorekeeping hardware were determined. These specifications follow:

1. The unit must be capable of performing only additive arithmetic to a maximum total of  $300_{10}$ . (Subscript = base)
2. Magnitude decision-making capabilities must be included.
3. There must be provisions to set and clear flags or reminders and further to later detect whether these flags are set or cleared.
4. The scorekeeping operation is basically a sequential process.
5. The sequence must be able to follow various branches depending on the magnitude decisions and depending on whether flags are set.
6. A considerable amount of timing is necessary to accomplish these sequences.
7. Working registers are needed.
8. A frame counter is needed.

These functional specifications led to the following design decisions:

1. Since only addition to  $300_{10}$  is required, and since this sum will be displayed; the decision was made to perform all arithmetic, and store all data, in 8-4-2-1 binary coded decimal (B.C.D.) form.
2. Flip-flops are used for flags and working registers.
3. The unit operates primarily as a sequential machine.
4. Monostable multivibrators provide timing.

5. Branching decisions are made by combinational logic.

Since the score must be kept for more than one person, storage is necessary. It was further decided that:

6. 4 x 4 semiconductor register files are suitable for the memory section.
7. A man-up counter is needed to indicate which bowler is bowling and provide memory address information.

## CHAPTER III

### A. General Discussion

The program discussed in Chapter 2 could be adapted for use in an existing minicomputer or mid-sized computer, which could keep score for one lane or all the lanes in a bowling alley. The Tactile-Audio Console could easily interface with such a computer. This thesis, however, deals with the design of a special purpose computer intended to be used on each lane; mainly because the unit serves such a specialized purpose.

It was decided that the console should be located on the score-keeping table presently in use. Also, it was decided to forego a printed copy or braille copy of the game initially, although it would be possible to add these features later. It was further decided to display only the essential information; more will be said about this decision in the section on the Tactile-Audio Console. The decision was made to initially rely on the present pin sensors used on pin setters, and to assume that a satisfactory interface to these pin sensors can be developed. This matter will also be discussed again later in the thesis. Transistor transistor logic (TTL) digital integrated circuits were used throughout the design because of their widespread use, ready availability, and low cost. The logical design uses standard functions, however, and other types of logic could also be used to implement this logic design. The general design of the hardware unit is shown in block diagram form in Figure 8.

### B. Information Displayed

Figure 9 is a detailed block diagram of the unit, showing the interconnections between the five major sections. The essential



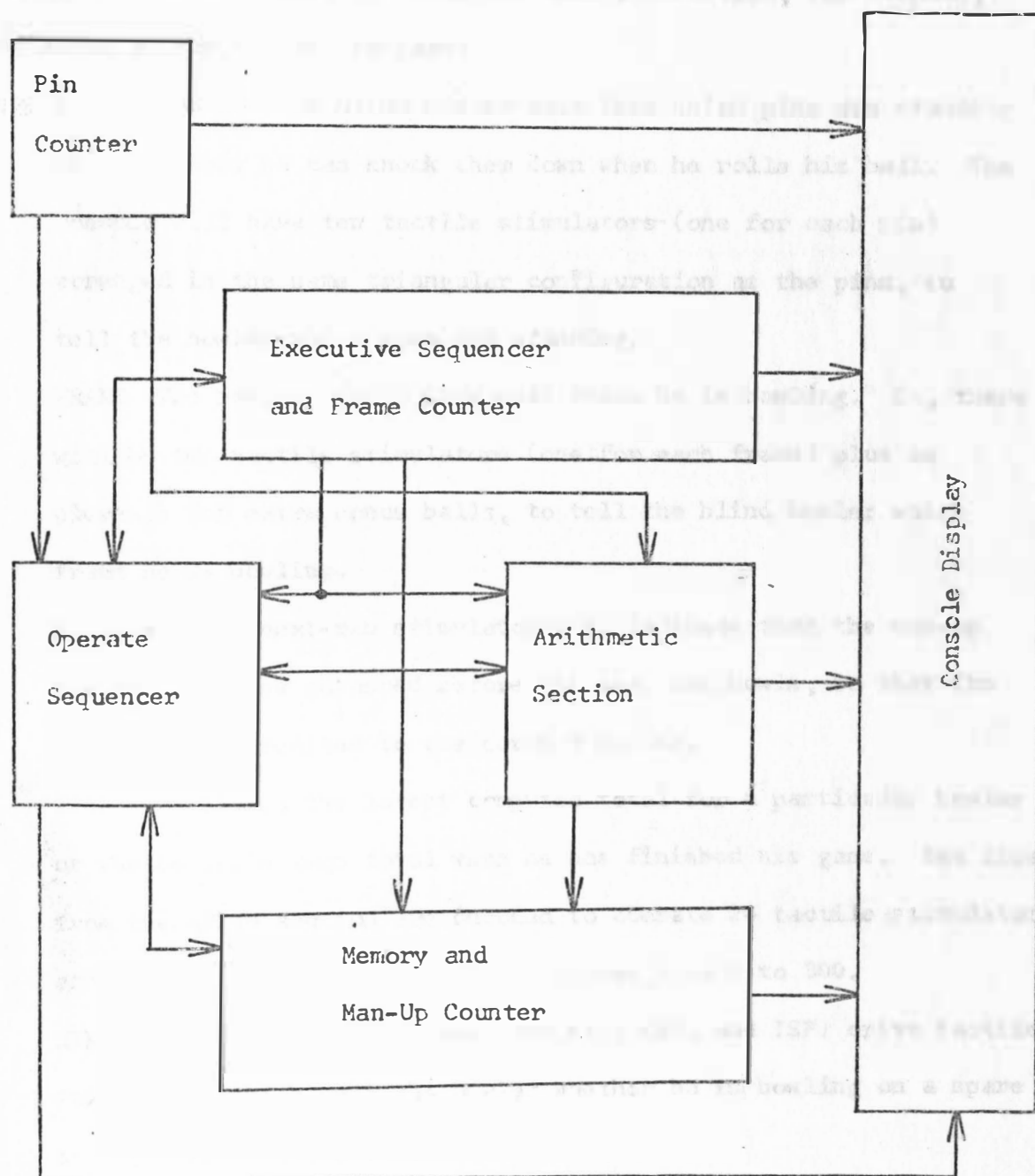


Figure 8. General Block Diagram.

information which will be displayed on the console is indicated along the right side of Figure 9. Consider this information, for display, beginning at the top of the page:

**PINS STANDING** The blind bowler must know which pins are standing in order that he can knock them down when he rolls his ball. The console will have ten tactile stimulators (one for each pin) arranged in the same triangular configuration as the pins, to tell the bowler which pins are standing.

**FRAME** The bowler should know what frame he is bowling. So, there will be ten tactile stimulators (one for each frame) plus an eleventh for extra bonus balls, to tell the blind bowler which frame he is bowling.

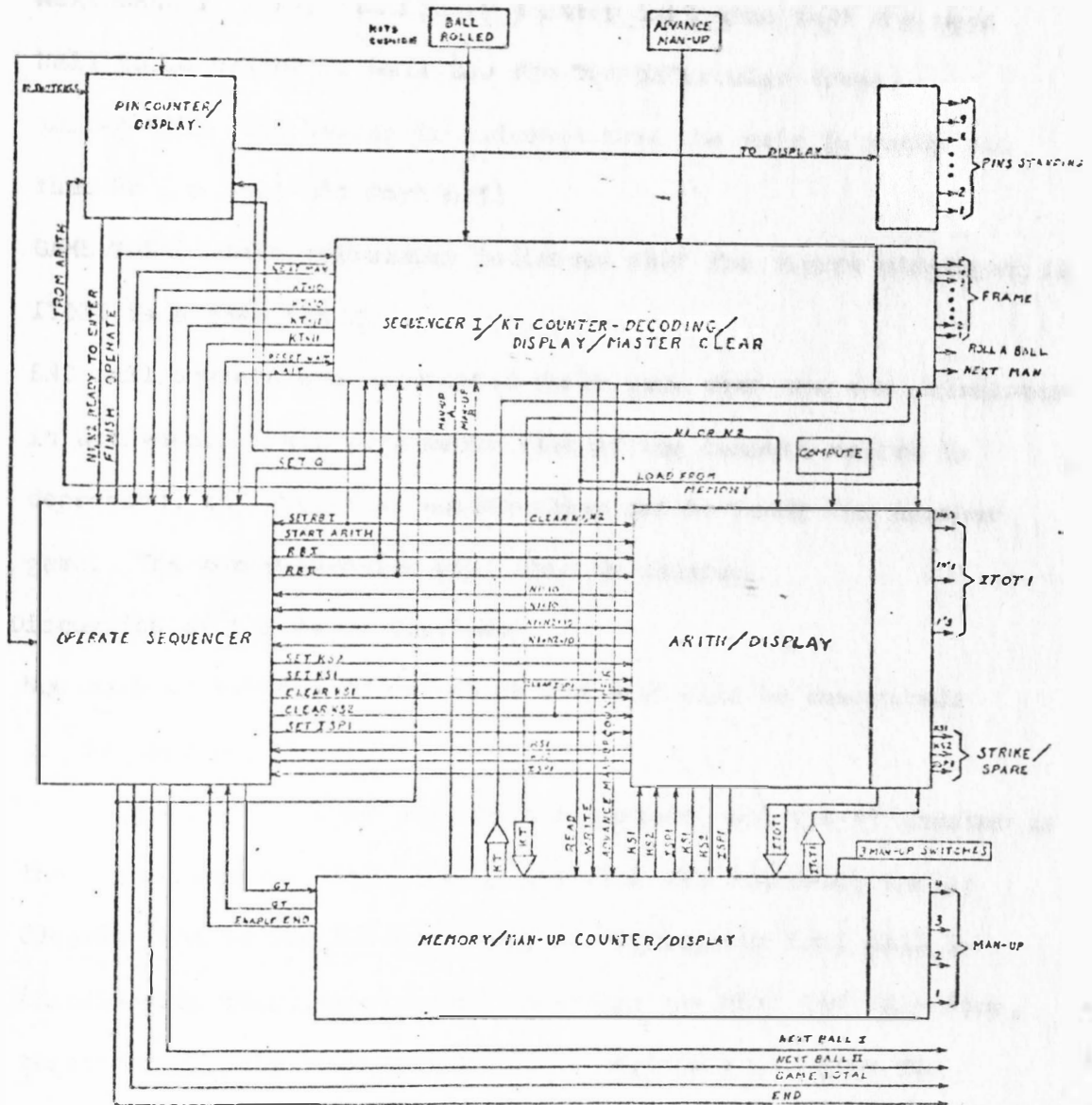
**NEXT MAN** The next-man stimulator will indicate that the man-up counter is to be advanced before the next man bowls, so that the pins will be credited to the correct bowler.

**ITOT1 - ITOT1** is the latest computed total for a particular bowler or the bowler's game total when he has finished his game. Ten lines from the ARITH section are decoded to operate 24 tactile stimulators arranged in positions to indicate scores from 0 to 300.

**STRIKE-SPARE** The three lines from KS1, KS2, and ISP1 drive tactile stimulators which tell the bowler whether he is bowling on a spare or a strike or two strikes.

**MAN-UP** The man-up stimulators indicate which man is bowling.

This initial design is for four bowlers or less. By simply adding memory storage, the unit could be designed to handle as many bowlers as desired.



NEXT BALL I This stimulator indicates that the next ball to be rolled is the first ball in a frame.

NEXT BALL II This tactile stimulator indicates that the next ball to be rolled is ball two for the particular frame.

ROLL-A-BALL The bowler is informed that the unit is ready and that he can roll his next ball.

GAME TOTAL This stimulator indicates that the figure displayed in ITOTI is a game total.

END All bowlers have completed their game when the end stimulator is activated. This also means that if the compute switch is depressed, the unit will master-clear and be ready for another game. The memory section will also be cleared.

#### C. Discussion of the Major Sections

Now each of the five sections of the unit will be described:

##### 1. Sequencer I

Sequencer I is the executive sequencer, and the KT counter is the frame counter. Sequencer I performs the following tasks: Clearing the N1 and N2 registers, presetting the Roll Ball 1 (R.B.1) flip flop, setting and resetting the NEXT MAN flip flop, transferring data from Memory to the registers and from the registers back to Memory, and also initiating the Operate Sequencer. The Operate Sequencer handles detailed timing and branching decisions and controls the arithmetic operations.

The Master Clear circuitry is also part of Sequencer I. The Master Clear operates when the power is first turned on in order to put the unit into the proper state to begin operation.

Master Clear is also used after each game to clear the unit in preparation for another game. The Master Clear operations performed on each of the five sections of the unit follow:

Sequencer I/KT counter

Set Wait

Reset Next-Man

Set KT = 1

Set Roll-A-Ball

Operate Sequencer

Set RB I

Reset RB II

Clear ISPI and KS2

Clear KSI

Clear END

Memory/Man-Up Counter/Display

Clear all memory storage

Set Man-Up to "One"

Arith/Display

Reset Compute

Clear N1, N2 and N1 + N2

Clear ITOTI Display

Pin Counter/Display

Clear shift register and counter

2. Operate Sequencer

The Operate Sequencer provides the decision-making logic and timing necessary to follow the flow chart previously discussed.

The Operate Sequencer is initiated from Sequencer 1 and it initiates the operation of the ARITH (arithmetic section). The Game Total and End flip-flops are also located in the Operate Sequencer.

### 3. Pin Counter/Display

As the name implies, this section counts the number of pins which have been knocked down. The pin sensors detect whether each pin is up or down and this information is displayed directly. The "pins-down" must also be counted so the number can be added to the previous total. A shift register and counter are used for this purpose. The necessary timing is also included in this section. The count is provided in B.C.D. form to the ARITH section.

### 4. Memory/Man-Up Counter/Display

This section handles data storage for those bowlers who are not presently bowling. For each, the following must be stored: ITOT1, KT, Game Total (GT), KS1, KS2, ISP1. The Man-Up counter and decoding also are included here. An Enable End signal is generated which must be high in order to set the End flip-flop.

### 5. Arith/Display Section

In addition to the fundamental arithmetic circuits, this section contains some timing, registers for N1 and N2, the ITOT1 display register, and the KS1, KS2, and ISP1 flip flops. Since little computation is required and since the results are always displayed, arithmetic is done (and data are kept) in 8-4-2-1 B.C.D. form. Code conversions are thus avoided. Four arithmetic operations

occur in computing bowling scores:

$$ITOT2 = \text{New } ITOT1 = \text{Old } ITOT1 + N1 + N2$$

$$ITOT2 = \text{New } ITOT1 = \text{Old } ITOT1 + N1 + N2 + 10$$

$$ITOT2 = \text{New } ITOT1 = \text{Old } ITOT1 + N1 + 10$$

$$ITOT2 = \text{New } ITOT1 = \text{Old } ITOT1 + N1 + 20$$

The arithmetic section is therefore a very specialized section designed to perform one of these four operations in B.C.D. and then display the new ITOTI (ITOT2). By using Master-Slave flip flops (where the input and output are never directly connected), it was possible to have just one ITOTI register even though there is an Old ITOTI and a New ITOTI.[5]

As shown in Figure 8 the B.C.D. binary numbers correspond exactly to the value of the decimal number which is represented.

<u>Decimal</u>	<u>Binary Coded Decimal</u>
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Figure 10. 8-4-2-1 Binary Coded Decimal.[6]

This means that ordinary binary addition can be used for each character; however, the sum of each decimal digit must be corrected to take care of carries to the next digit and sums which have binary values 10 through 19 (with carry-in's).

Figure 11 shows that with a possible carry-in, 20 different sums can be produced of which only 10 will be correct.

DECIMAL	Uncorrected BCD Sum $C_4E_4E_3E_2E_1$	Corrected BCD Sum $C_4E_4E_3E_2E_1$	
0	0000	0000	} No Correction RQ'D
1	0001	0001	
2	0010	0010	
3	0011	0011	
4	0100	0100	
5	0101	0101	
6	0110	0110	
7	0111	0111	
8	1000	1000	
9	1001	1001	
-----			
10	1010	10000	} Correction RQ'D
11	1011	10001	
12	1100	10010	
13	1101	10011	
14	1110	10100	
15	1111	10101	
16	10000	10110	
17	10001	10111	
18	10010	11000	
19	10011	11001	

Figure 11. B.C.D. Sums Needing Correction.[7]

The necessary correction can be made by subtracting  $10_{10}$  (subscript=base) and generating a carry to the next digit.[8] This was implemented by adding the 2's complement of the BCD representation of  $10_{10}$  ( $1010_2$ ), which is  $0110_2$  in BCD or decimal 6.[9] The Karnaugh map for the decoding scheme which controls when 6 is added and the carry generated is shown in Figure 12.



$\sum_4 \sum_3$   $\sum_2 \sum_1$

	00	01	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

$\sum_4 \sum_3 + \sum_4 \sum_2$

Figure 12. Karnaugh Map. [10]

The results of the Karnaugh map (which considers only 16 possible results) are combined with a possible carry-out signal to detect sums of  $10_{10}$  through  $19_{10}$  as follows:

$$C_n = C_4 + \sum_4 \sum_3 + \sum_4 \sum_2$$

The B.C.D. adder used in this design is shown in Figure 13. As mentioned this adder is corrected by a 2's complement addition, and it has carry-out capabilities. [11]

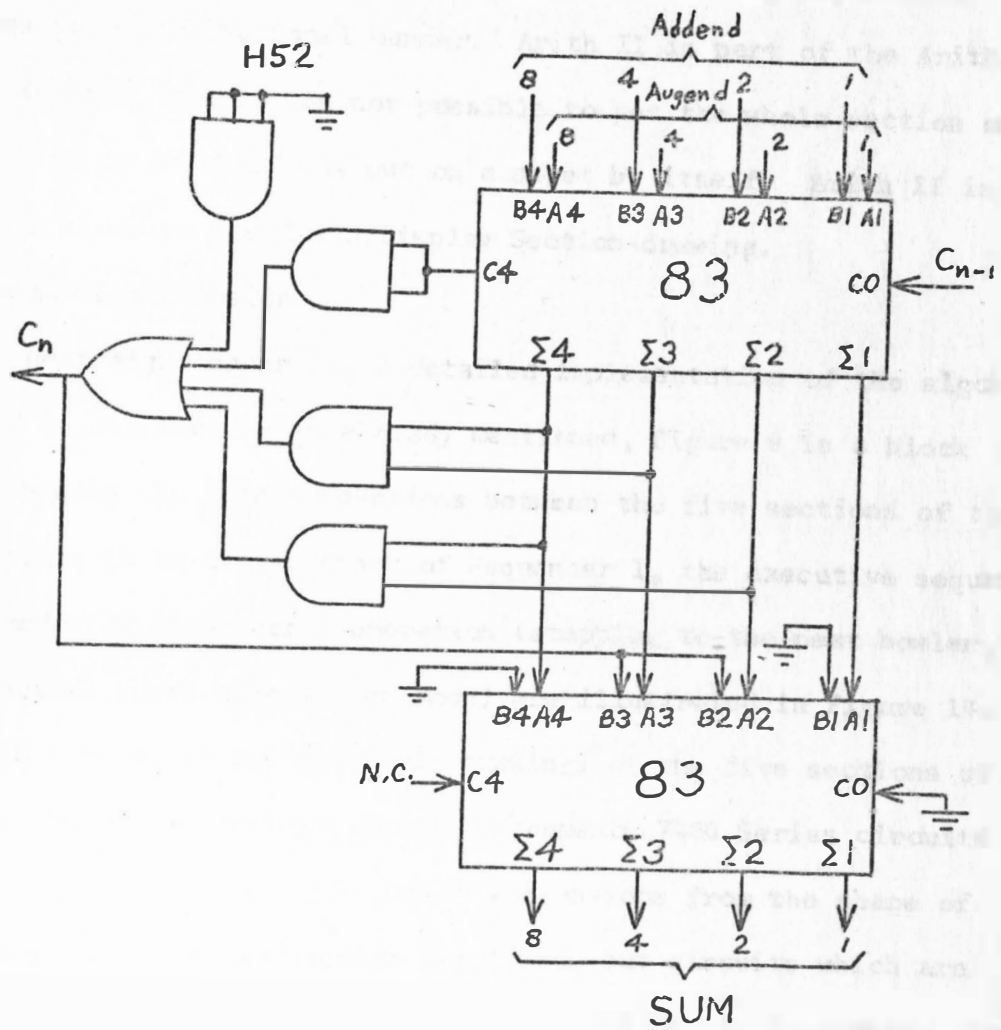


Figure 13. B.C.D. Adder Stage.[12]

Two such adders, each capable of adding to  $300_{10}$ , were used along with some combinational logic to perform the four necessary arithmetic functions in a combinational manner. Arith II is part of the Arith/Display Section, but it was not possible to get the whole section on one drawing, so Arith II was put on a sheet by itself. Arith II is shown as a block on the Arith/Display Section-drawing.

#### D. Detailed Logic Design

The next eight pages are a detailed implementation of the algorithm discussed in Chapter 2. As already mentioned, Figure 9 is a block diagram showing the interconnections between the five sections of the unit. Figure 14 is a flow chart of Sequencer I, the executive sequencer. The two modes of Sequencer I operation (stepping to the next bowler, and the actual score computation mode) are illustrated in Figure 14. Figures 15 through 20 are the logic drawings of the five sections of the unit. In these drawings, Texas Instruments 7400 Series circuits are used. "And gates" and "Or gates" are obvious from the shape of their symbols and are not further specified, but circuits which are represented by boxes contain the last digits of the T. I. number. For instance, 121 corresponds to an SN74121 monostable. The reader can find these circuits in the T. I. Integrated Circuits Catalog.

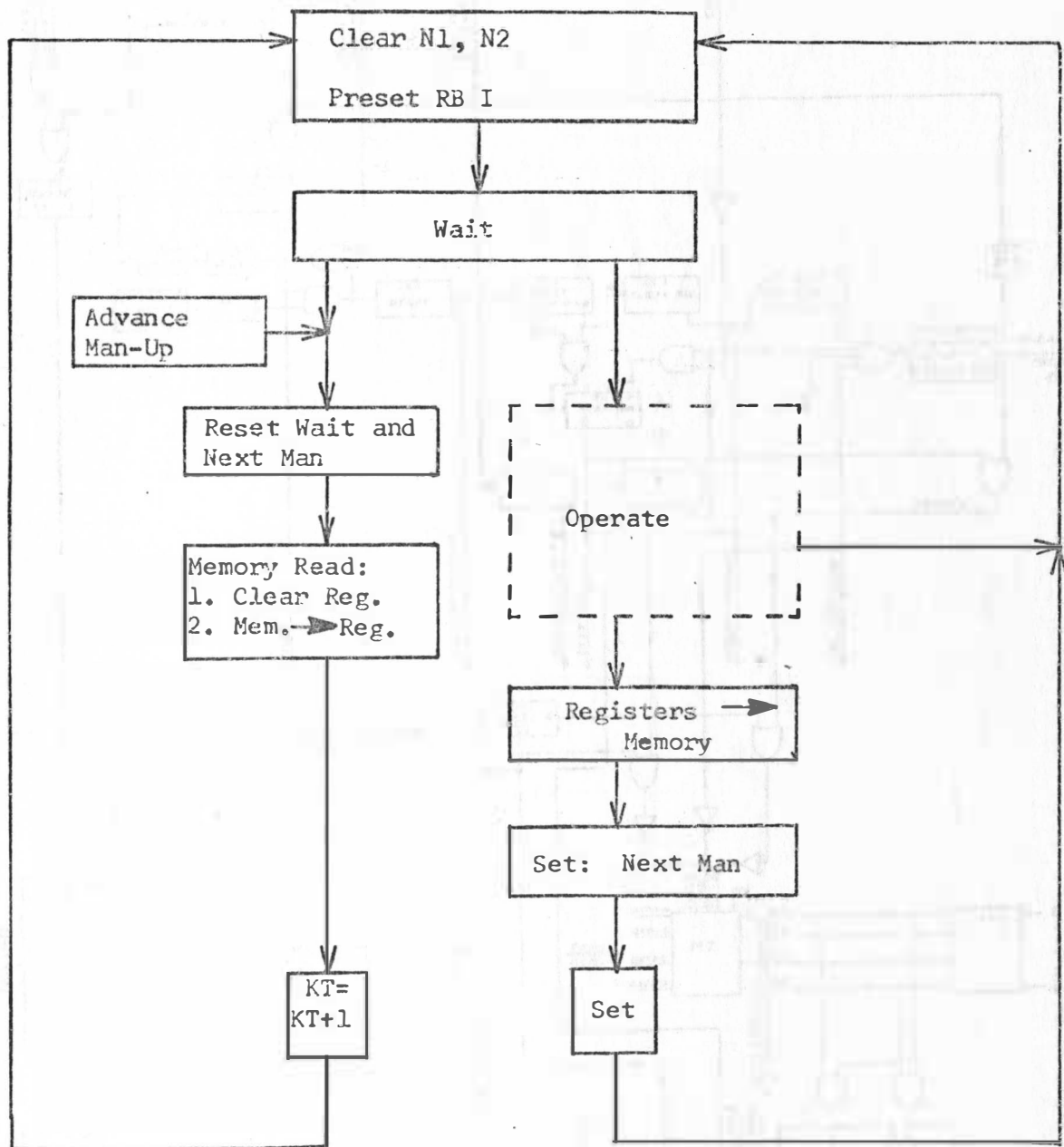


Figure 14. Sequencer I Flow.

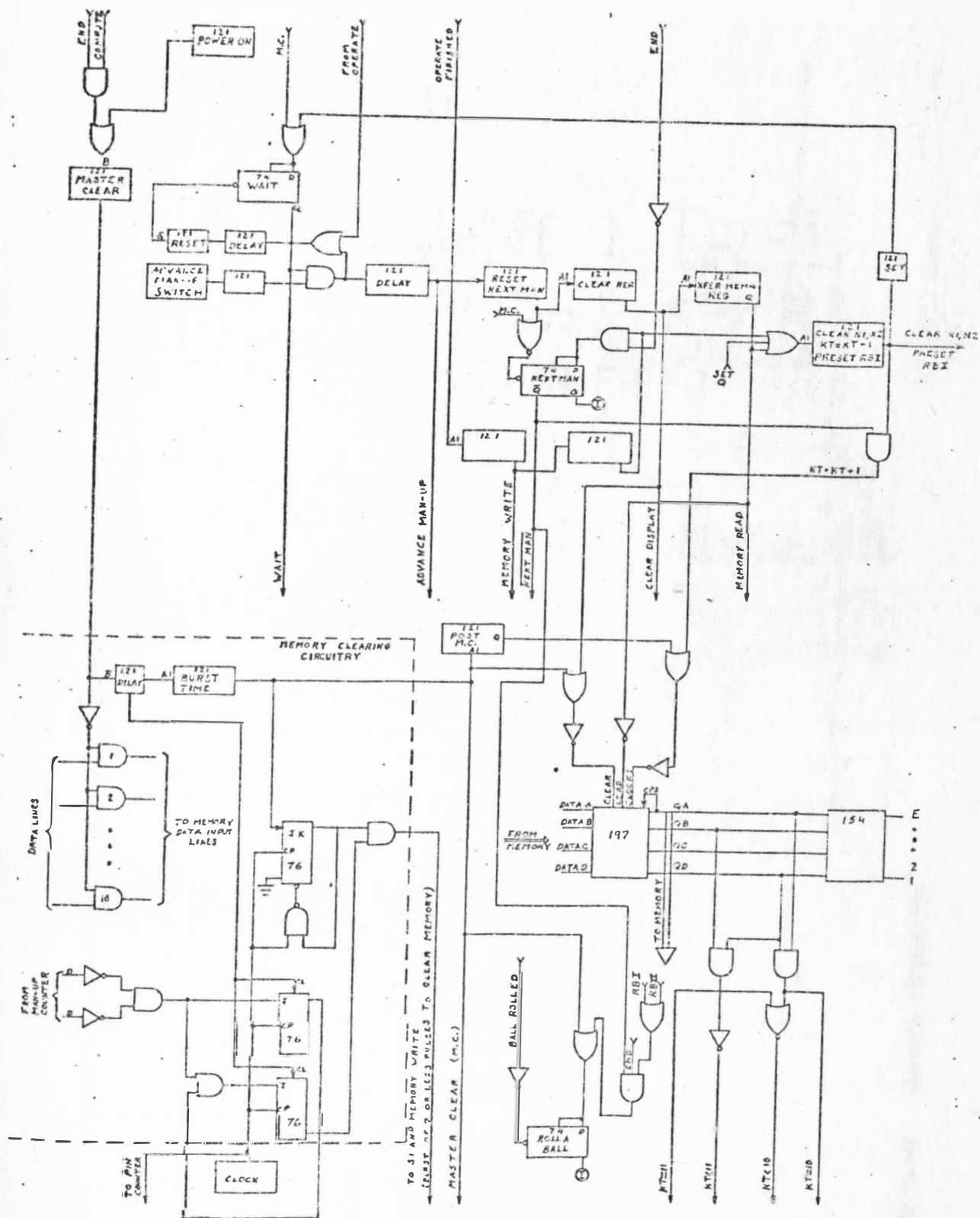


Figure 15. Sequencer I/KT Counter/Master Clear.





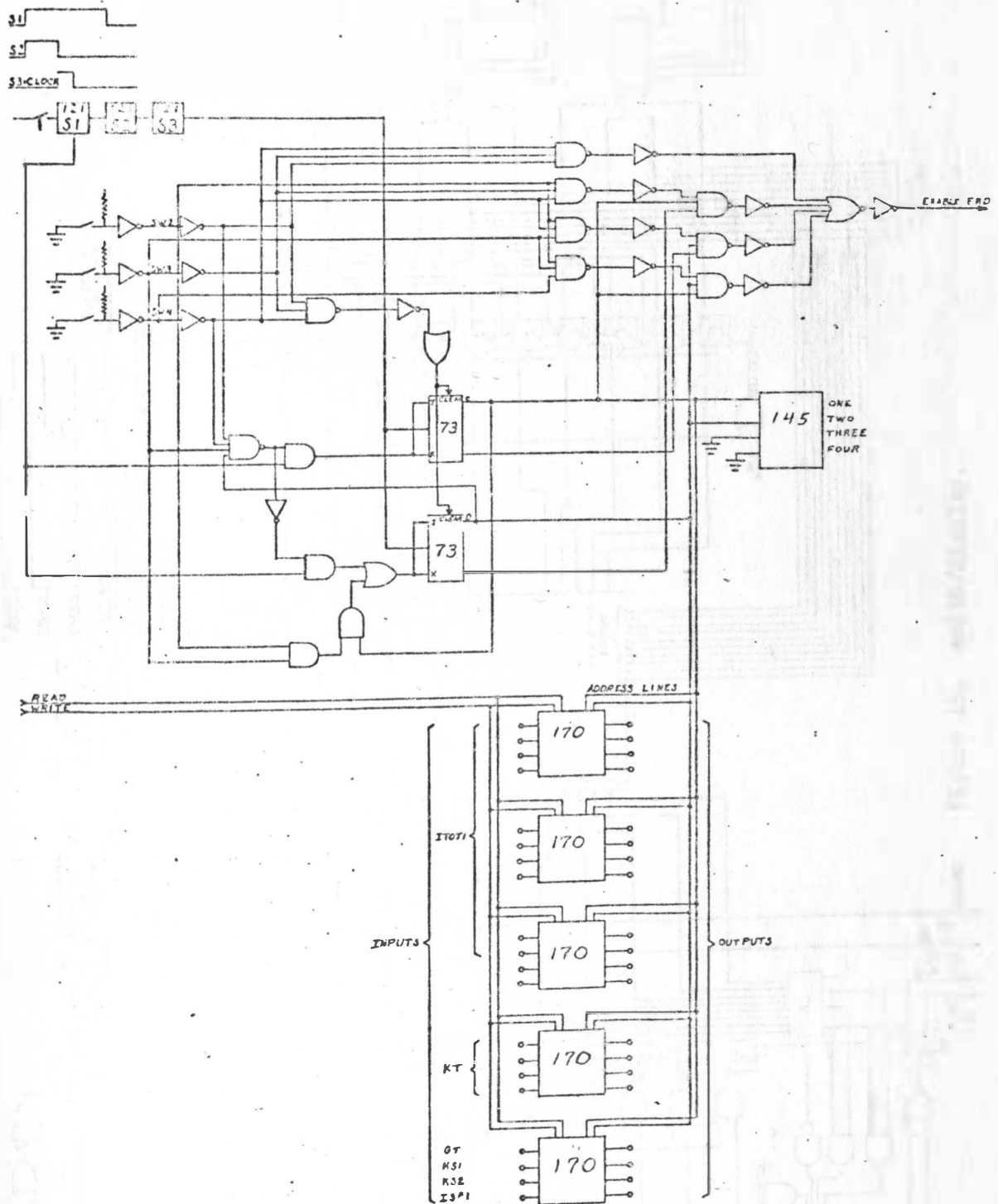
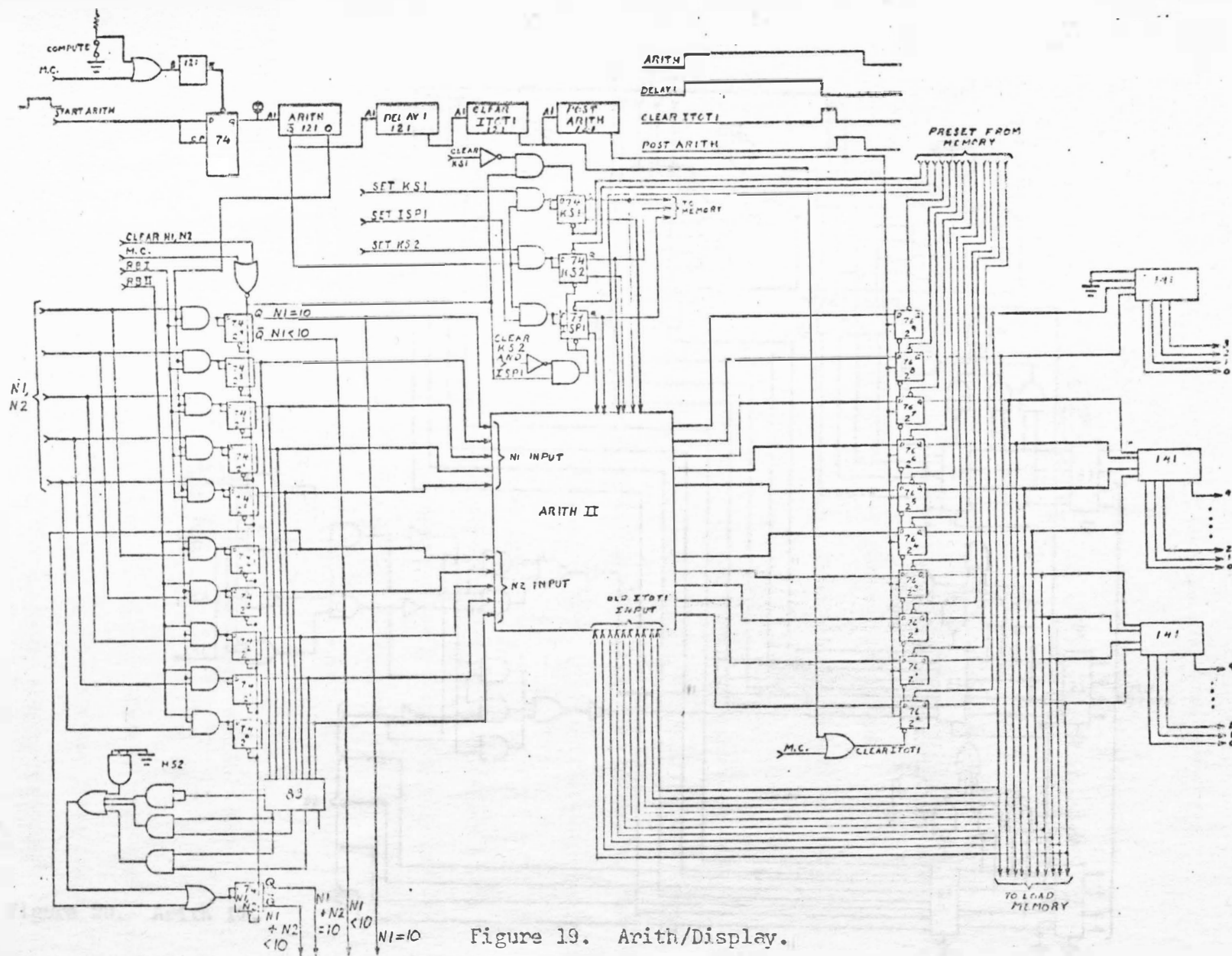


Figure 18. Memory/Man-Up Counter.





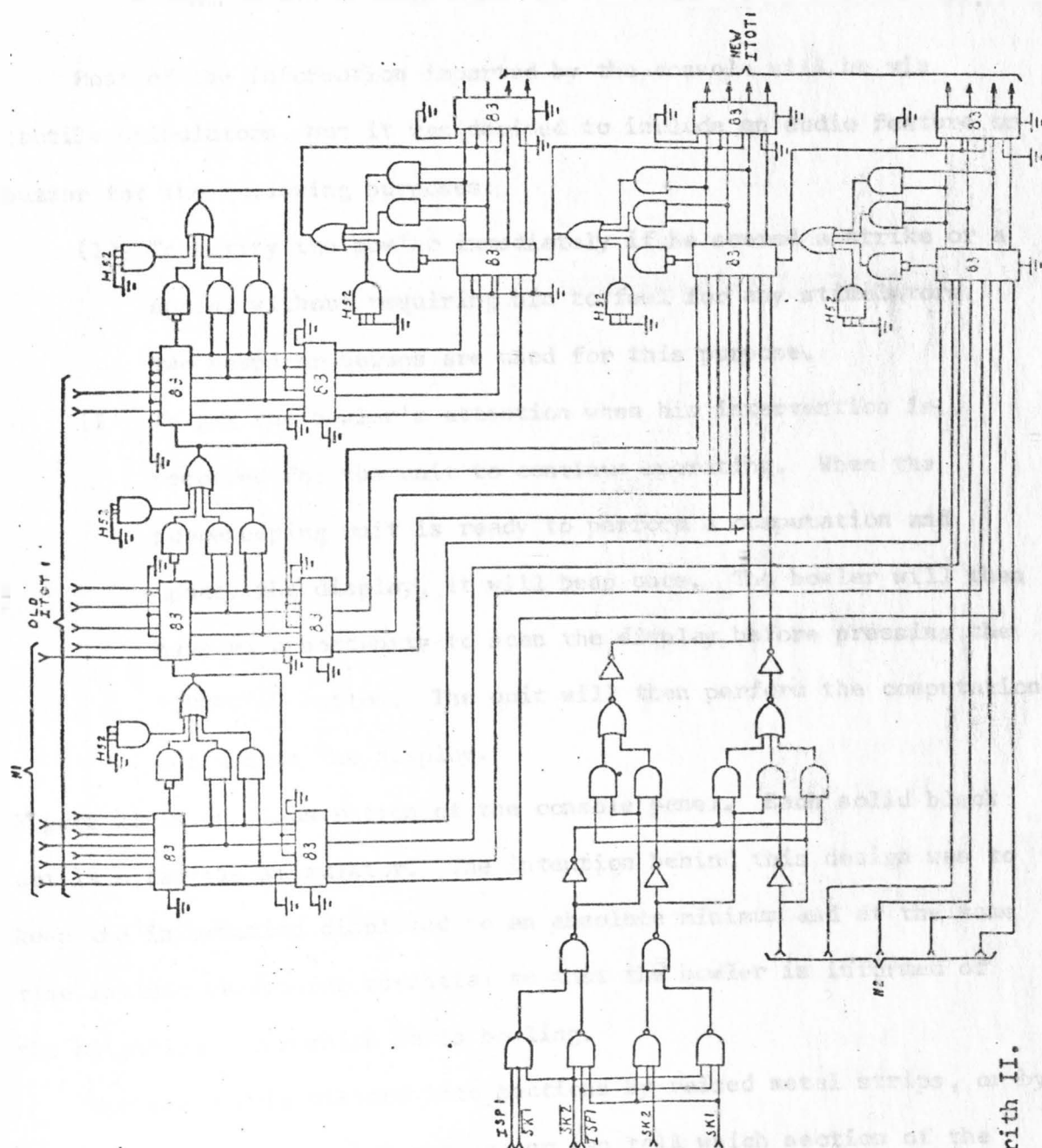


Figure 20. Arith II.

## CHAPTER IV

## Design of the Tactile-Audio Console for Blind Bowlers

Most of the information imparted by the console will be via tactile stimulators, but it was decided to include an audio feature or buzzer for the following purposes:

- (1) To notify the bowler immediately if he scored a strike or a spare, without requiring him to feel for any stimulators. Two beeps or buzzes are used for this purpose.
- (2) To get the bowler's attention when his intervention is required for the unit to continue operating. When the scorekeeping unit is ready to perform a computation and update the display, it will beep once. The bowler will then have an opportunity to scan the display before pressing the "COMPUTE" button. The unit will then perform the computation and update the display.

Figure 21 is an illustration of the console panel. Each solid black dot is a tactile stimulator. The intention behind this design was to keep the information displayed to an absolute minimum and at the same time include everything essential so that the bowler is informed of the situation under which he is bowling.

The console is divided into sections by raised metal strips, or by depressed notches, so that the bowler can tell which section of the console he is scanning by feeling these dividers. Notice that the top of the console is divided into four boxes, the center two boxes being further subdivided. These four boxes correspond roughly to four



bowling frames. The differences between these four boxes and four conventional bowling frames are pointed out in Figure 22. The bowler's last computed frame total is always displayed in the left-most box. The right-most box tells him two things: (1) The frame he is presently bowling and (2) whether his next ball will be ball 1 or ball 2.

The two center boxes at the top of the console tell the bowler whether he is bowling on strikes or a spare. If the stimulator in the lower half of the left-most center box is activated, the bowler knows he is bowling on a spare. If the stimulator in the half-box immediately above the spare indicator is activated, the bowler knows he is bowling on one strike. While if this stimulator is activated and the stimulator in the right-most of the two center boxes is activated, the bowler knows he is bowling on two strikes. The stimulators in these four boxes tell the bowler all essential information about his score.

Below the left-most box at the top of the console (last computed total) is a small box containing two stimulators. The Game Total stimulator is activated if the score in the "Last Computed Total" box is the total game score for that bowler. If all bowlers have completed their game, both the Game Total and "End" stimulators are activated. By repeatedly pressing the Advance Man-Up button, one can step through the game totals for the bowlers.

Below the box containing Game Total and End is the box containing the stimulators which indicate which bowler is "up" to bowl. The console shown in Figure 21 is designed for a maximum of four bowlers. This number could easily be increased. The Advance Man-Up button

advances the Man-Up counter and activates the next man's stimulator. The three switches beside the upper three stimulators are to be used when there are less than four bowlers. If there are only three bowlers, the upper switch is turned off, while if there are only two bowlers, the two upper switches are both turned off, and so on.

In the lower center of the console, the box containing the ten stimulators representing the ten pin configuration, is located. The stimulators which are activated represent pins standing.

The final box on the console is located on the lower right side. The Roll-A-Ball stimulator is activated when the unit is ready for the bowler to roll a ball. The Next Man stimulator is activated when a bowler has completed bowling his frame and the Advance Man-Up button must be pressed once to ready the unit for the next bowler. The Compute stimulator, beside the Compute button, is activated when the unit is waiting for the bowler to press the Compute button to tell the unit to perform the computation and update the display. In addition to activating the Compute stimulator, the unit also beeps once to get the bowler's attention. On the other side of the Compute button is a switch which can be used to disable the Compute button. When this switch is turned off, the unit does not wait for the Compute button to be depressed before performing the computation; it performs the computation immediately.

Briefly, this is one console display that could be used. This console could be further simplified, but it was felt that further simplification could be confusing. The console could also be made more complete and more like the conventional score sheet, but it would then

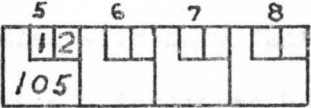
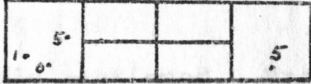
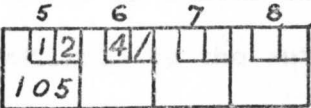
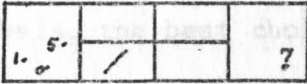
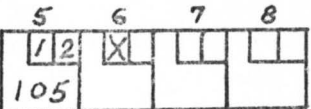
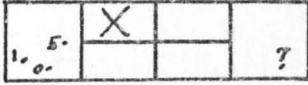
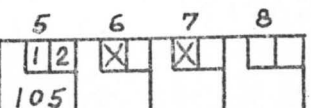
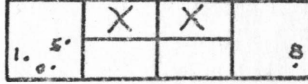
Four Conventional Bowling Frames	Console Display
	
	
	
	

Figure 22. Comparison of Console with Conventional Bowling Frames.

be more complex and more costly. All of the action in bowling can be shown in a maximum of four frames, so the decision was made to basically display four frames. As shown in Figure 22, the four boxes at the top of the console do not directly correspond to four bowling frames, but they do display all really essential information. So, this console is a compromise with many factors considered.

Tactile stimulators have been repeatedly mentioned. Various kinds of stimulators could be used; in fact the tactile stimulator area is almost a field in itself where much work could be done. From the information available to the author of this thesis, the best choice of stimulators seems to be the piezoelectric vibrator or bimorph. [13]



## CHAPTER V

## Areas Needing More Work

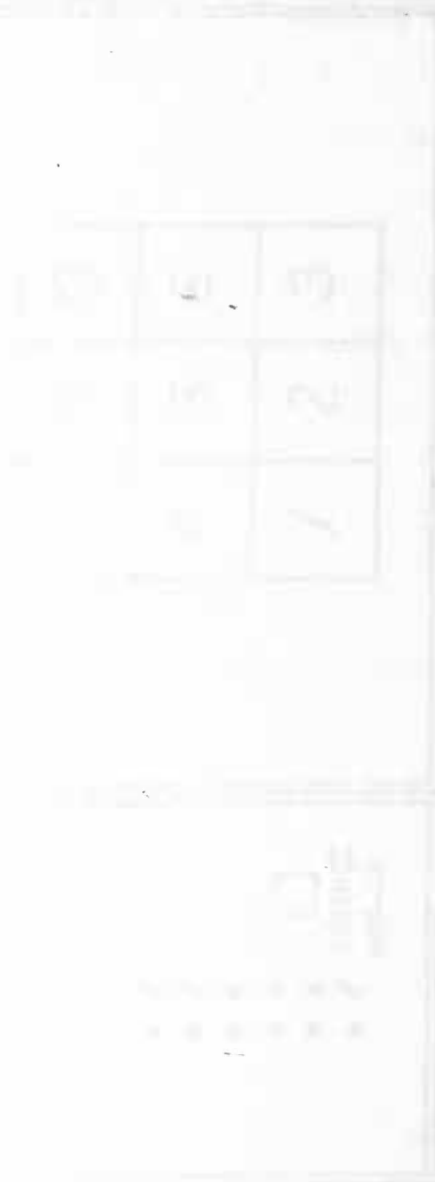
Once this basic design is perfected and all the "bugs" are worked out of it, there are many other features that should be added. For example, the unit should interface with the foul line sensor. Also, some special operating modes may be necessary for use in tournament games where several alleys are used and the teams alternate alleys. Of course, one very important area where more work is needed is in providing a paper copy of the score sheet - either a printed copy or a braille copy or both. Interfacing a printer or braille printer to the unit should not be too difficult, but these devices are expensive and require more maintenance than totally electronic equipment. Perhaps one area worth investigating would be the use of a tape cassette for memory, and then after the bowlers are finished, they could remove the cassette from the scorekeeping unit, take it to the front desk where the attendant could insert it in a separate printing or braille printing unit if a paper copy is desired. This scheme would be economical because a printer would not be required for each lane; perhaps one printer for every ten lanes would be sufficient. A further economy feature would be the dual use of the cassette - both as the memory for the scorekeeping unit, and to transfer the information to the printing unit. More circuitry would be required to control the tape motion.

Another area where considerable work could be done is the pin sensor area. The pin sensors presently in use are micro-switches on the automatic pin setting rack. The assumption was made that this

scorekeeping unit would interface with these pin sensors presently in use. However, this would mean that this scorekeeping unit would have to be permanently installed in the bowling alley or at least a plug, where it could be plugged in, would have to be installed in the alley. In either case, the bowling alley would have to be modified. The ideal scorekeeping unit for the blind would be a completely self-contained unit that could be carried into the bowling alley and easily set up. Such a unit would require a breakthrough in pin sensing equipment, though. Optical pin sensors seem to hold the most promise, but to optically sense pin-fall from the far end of the alley would require new pattern recognition equipment. Optical pin sensing from above the pins seems to hold promise, but installation and breakage might be problems. Perhaps a carry-in unit could easily interface with some of the new bowling equipment. For example, a pin finder is usually installed on the ball return with Brunswick's new Automatic Scorer. A plastic "cap" with photo-diodes to detect which pins are downed, could be fitted over the Brunswick pin finder. The console and computer discussed in this thesis along with such a "cap" could all be battery powered. This combination would be a very convenient carry-in unit, and would require no modification of the bowling alley.

One final area that could be explored, is modifying this unit for the blind, for use by sighted bowlers. An interesting possibility is to convert this unit to a pocket calculator with a manual entry keyboard and seven segment displays - a pocket bowling calculator for bowlers who can see. Only a very minimum of logic modifications would be required;

in fact, probably the same printed circuit board could be used for a calculator for sighted bowlers as is used for the unit for the blind. As shown in Figure 23, only two of the boxed-in panels on the front of the console would have to be changed. Light emitting diodes would be substituted for the tactile stimulators in the other panels. In this way we could have a compact, low powered, battery-operated calculator requiring just one 5 volt supply.



<p>LAST COMPUTED TOTAL</p> <div style="border: 1px solid black; display: inline-block; width: 40px; height: 40px; text-align: center; line-height: 40px; margin: 5px;">3</div> <div style="border: 1px solid black; display: inline-block; width: 40px; height: 40px; text-align: center; line-height: 40px; margin: 5px;">0</div> <div style="border: 1px solid black; display: inline-block; width: 40px; height: 40px; text-align: center; line-height: 40px; margin: 5px;">0</div>	<div style="border: 1px solid black; width: 100%; height: 100%; position: relative;"> <div style="position: absolute; top: 50%; left: 50%; transform: translate(-50%, -50%) rotate(45deg); width: 50px; height: 50px; border: 1px solid black;"></div> <div style="position: absolute; top: 50%; left: 50%; transform: translate(-50%, -50%) rotate(-45deg); width: 50px; height: 50px; border: 1px solid black;"></div> </div>	<div style="border: 1px solid black; width: 100%; height: 100%; position: relative;"> <div style="position: absolute; top: 50%; left: 50%; transform: translate(-50%, -50%) rotate(45deg); width: 50px; height: 50px; border: 1px solid black;"></div> <div style="position: absolute; top: 50%; left: 50%; transform: translate(-50%, -50%) rotate(-45deg); width: 50px; height: 50px; border: 1px solid black;"></div> </div>	<div style="text-align: center; margin-bottom: 20px;"> <div style="display: inline-block; text-align: center; margin-right: 20px;"> <sup>1</sup> ● NEXT BALL         </div> <div style="display: inline-block; text-align: center;"> <sup>2</sup> ●         </div> </div> <p>THIS FRAME:</p> <div style="display: flex; justify-content: space-around; font-size: small;"> <span>● 1</span><span>● 2</span><span>● 3</span><span>● 4</span><span>● 5</span><span>● 6</span><span>● 7</span><span>● 8</span><span>● 9</span><span>● 10</span><span>● E</span> </div>												
<div style="margin-bottom: 10px;">● GAME TOTAL</div> <div>● END</div>	<table border="1" style="width: 100%; height: 150px; border-collapse: collapse; text-align: center; font-size: 2em;"> <tr><td>X</td><td>/</td><td></td></tr> <tr><td>7</td><td>8</td><td>9</td></tr> <tr><td>4</td><td>5</td><td>6</td></tr> <tr><td>1</td><td>2</td><td>3</td></tr> </table>		X	/		7	8	9	4	5	6	1	2	3	<div style="margin-bottom: 20px;">● ROLL A BALL</div> <div>● NEXT MAN</div> <div style="margin-top: 40px; text-align: center;"> <div style="border: 1px solid black; display: inline-block; padding: 5px 10px;">COMPUTE</div> <span style="font-size: 2em; margin-left: 10px;">8</span> </div>
X	/														
7	8	9													
4	5	6													
1	2	3													
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> <div style="display: flex; flex-direction: column; gap: 5px;"> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> </div> <div style="display: flex; flex-direction: column; gap: 5px;"> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> <div>● 8</div> </div> </div> <div style="text-align: center; margin-top: 10px;"> <div style="border: 1px solid black; width: 20px; height: 20px; margin: 0 auto; margin-bottom: 5px;"></div> <div>ADVANCE MAN-UP</div> </div> </div>															

Figure 23. Bowling Calculator.

## CHAPTER VI

## Summary of Conclusions and Recommendations

Probably the most important conclusion reached in the course of this work, is that it is now feasible to actually produce a unit such as this. The author of this thesis believes that a unit could be produced that would be convenient enough and economical enough so that it would be available to many blind bowlers. If such a unit were available, perhaps blind bowling would grow, creating a need for a larger number of units. Such an increase in production would reduce the price of the units further.

A rough analysis of the cost of the unit was conducted. The integrated circuits and printed circuit boards would cost approximately \$400.00 in small quantities. The cost of the tactile stimulators could not be determined, but assuming they would cost \$200.00, the parts cost for the unit would be \$600.00. The rule-of-thumb for retail price is 3 to 5 times the parts cost. The price of three times the parts cost is only for fairly high volume production so, for this unit, the price would probably range between \$2500.00 to \$3000.00.

The unit could either be sold or leased. Most leases for this type of equipment are 3 to 5 years. If the lessor plans to pay for the unit in two years, a typical rent figure might be \$125.00 per month. Using a 25 day month, the unit would then need to earn \$5.00 per day.

The author of this thesis believes that the most promising approach is that which interfaces to Brunswick's new pin finder by simply sliding a plastic "cap", containing light detecting diodes, over

the pin finder. The unit would be powered by rechargeable batteries. Such an approach would require no modification of the bowling alley, and this would be very convenient. The unit could be owned or leased by either the bowling alley or a blind bowling league.

A sidelight area where more work could be done, which would benefit all bowlers, is in the pin sensor area. A good practical optical pin sensing arrangement would be a great improvement over the microswitches now in use. Another promising area is a bowling calculator for bowlers to use in alleys which do not have automatic scorekeeping equipment.

In this thesis, a bowling score algorithm was first discussed and verified. Then an implementation of the algorithm was discussed, and some discussion of the cost was included in an attempt to gauge the feasibility of producing this unit. The author of this thesis acknowledges that more work must be done in this area before there is any real benefit to blind bowlers. It is the sincere wish of the author of this thesis that this work can be continued, and that it will help to make life better for blind people.

## BIBLIOGRAPHY

1. "Introducing the American Blind Bowling Association." pp. 1-4.
2. United States Patent 3,550,939 Dec. 29, 1970.  
 United States Patent 3,385,600 May 28, 1968.  
 United States Patent 3,402,930 Sept. 24, 1968.  
 United States Patent 3,484,107 Dec. 16, 1969.  
 United States Patent 3,506,264 April 14, 1970.  
 United States Patent 3,589,725 June 29, 1971.  
 United States Patent 3,310,659 March 21, 1967.  
 United States Patent 3,499,649 March 10, 1970.  
 United States Patent 3,300,213 Jan. 24, 1967.  
 United States Patent 3,295,849 Jan. 3, 1967.  
 United States Patent 3,516,665 June 23, 1970.  
 United States Patent 3,565,428 Feb. 23, 1971.  
 United States Patent 3,582,071 June 1, 1971.
3. Bellissimo, Lon and Larry L. Neal. Bowling, New Jersey: Prentice-Hall, Inc., p. 12, 1971.
4. Bellissimo, Lon and Larry L. Neal. Bowling, New Jersey: Prentice-Hall, Inc., p. 13, 1971.
5. Staff of Texas Instruments, Incorporated. The Integrated Circuits Catalog for Design Engineers, pp. 6-58.
6. Morris, Robert L. and John R. Miller. Designing with TTL Integrated Circuits, Texas Instruments Electronics Series, New York: McGraw-Hill Inc., p. 226, 1971.
7. Morris, Robert L. and John R. Miller. Designing with TTL Integrated Circuits, Texas Instruments Electronics Series, New York: McGraw-Hill Inc., p. 226, 1971.
8. Morris, Robert L. and John R. Miller. Designing with TTL Integrated Circuits, Texas Instruments Electronics Series, New York: McGraw-Hill Inc., p. 226, 1971.
9. Lewin, Douglas. Logical Design of Switching Circuits, New York:

American Elsevier, Inc., pp. 6-8, 1968.

10. Lewin, Douglas. Logical Design of Switching Circuits, New York: American Elsevier, Inc., pp. 42-47, 1968.
11. Morris, Robert L. and John R. Miller. Designing with TTL Integrated Circuits, Texas Instruments Electronics Series, New York: McGraw-Hill Inc., p. 227, 1971.
12. Morris, Robert L. and John R. Miller. Designing with TTL Integrated Circuits, Texas Instruments Electronics Series, New York: McGraw-Hill Inc., p. 227, 1971.
13. Plummer, J. D. and J. D. Meindl. "MOS Electronics for a Portable Reading Aid for the Blind", IEEE Journal of Solid-State Circuits, Vol. SC-7, No. 2, p. 111, April, 1972.